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Results of the Weeks Island Strategic Petroleum Reserve Oil Leak Risk Assessment Study

Martin A. Molecke, Thomas E. Hinkebein, Stephen J. Bauer, and James K. Linn

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Abstract

This study evaluated multiple, long-term environmental oil-contamination risk scenarios that could result from the potential leakage of up to 1.5 million barrels of crude oil entombed in the Weeks Island SPR mine following site decommissioning and abandonment, and up to 100 years thereafter. This risk assessment also provides continuity with similar risk evaluations performed earlier and documented in the 1995 DOE *Environmental Assessment for Decommissioning the Strategic Petroleum Reserve Weeks Island Facility* (EA). This current study was requested by the DOE to help them determine if their previous Finding of No Significant Impact (FONSI), in the EA, is still valid or needs to be rescinded. Based on the calculated environmental risk results (in terms of clean-up and remediation expenses) presented in this risk assessment, including the calculated average likelihoods of oil release and potential oil-leakage volumes, **none of the evaluated risk events** would appear to satisfy the definition of **"significant environmental impact"** in National Environmental Policy Act (NEPA) terminology. The DOE may combine these current results with their earlier evaluations and interpretations in the 1995 EA in order to assess whether the existing FONSI is still accurate, acceptable, and valid. However, from a risk evaluation standpoint, the assessment of impacts appears to be the same whether only 10,000 to 30,000 barrels of crude oil (as considered in the 1995 EA), or up to 1.5 million barrels of oil (as considered herein) are abandoned in the Weeks Island SPR facility.

Acknowledgments

The authors would like to acknowledge the continued support of Jerry Berndsen, DOE SPR PMO, who initiated this study. In particular, we must acknowledge the major assessment inputs, contributions, and suggestions provided by all six of the selected, knowledgeable panel members: Paul L. Davidson, Dr. Thomas Magorian, Dr. Edward Overton, Charles G. Smith, Stewart Thompson, and Dr. Robert Thoms. We would like to thank David Brine, DOE SPR PMO, for offering many useful comments and suggestions for improving the report. Thanks are also extended to Brian Ehgartner and Darrell Munson, Sandia National Laboratories, for providing comprehensive and helpful technical reviews of this document.

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1.0 Executive Summary

This report documents the results of a formal Weeks Island SPR risk assessment study we conducted to support the Department of Energy (DOE), Strategic Petroleum Reserve Project Management Office (SPR PMO). This study semi-quantitatively evaluated multiple, long-term environmental contamination risk scenarios that could result from the potential leakage of up to 1.5 million barrels of crude oil entombed in the Weeks Island SPR mine following site decommissioning and abandonment, and up to 100 years thereafter. A major, supportive purpose of this risk assessment study is to provide continuity with similar, earlier risk evaluations performed and documented by the DOE in the *Environmental Assessment for Decommissioning the Strategic Petroleum Reserve Weeks Island Facility* (EA), [DOE, 1995]. The 1995 DOE EA considered the potential impacts of abandoning approximately 10,000 to 30,000 bbl of crude oil. Consistent with currently known information and decommissioning activities at the Weeks Island facility, the present risk assessment evaluates the potential risks of environmental impact (within the meaning the National Environmental Policy Act, NEPA) of abandoning a much larger volume of crude oil. This support study was conducted both to quantify the risks and to help the DOE determine if their previous Finding of No Significant Impact (FONSI), in the EA [DOE, 1995] is still valid or needs to be rescinded.

The specific risk scenarios in this current study were evaluated by a select group of six independent, knowledgeable panel members. Almost all of these panel members had significant prior knowledge and understanding of the past operations and/or geology of the Weeks Island SPR facility and environs. Panel members were presented with details on the current status of this facility, including: ongoing and planned decommissioning operations and concerns, possible mechanisms for both long-term oil entrapment or potential escape from the facility, and other associated information. They were then asked to individually evaluate (in terms of specific value ranges) the likelihood (probability) and consequence (severity) of each of the defined, potential risk events, to the best of their knowledge. The overall risks were then calculated, using a Delphi methodology, and interpreted. With this methodology, the calculated *risk* equals the product of the *likelihood* times the *consequence* for each risk event. Potential long-term *consequences* and *risks* are stated in terms of dollars, i.e., expenses specifically for oil contamination clean-up and facility remediation costs *only*. Potential legal or regulatory compliance expenses are not predictable and were not considered in this assessment study.

Three important risk scenarios were evaluated, as follows:

Scenario 1. The potential long-term (within 100 years) environmental contamination of groundwater and sediments above the Weeks Island salt dome due to oil leakage.

Scenario 2. The potential long-term (within 100 years) environmental contamination of the surface waters surrounding the Weeks Island site, into Weeks or Vermilion Bay.

Scenario 3. The potential consequences of oil leakage into the nearby Morton Salt Mine, following its eventual abandonment, and subsequent long-term environmental contamination, as in risk scenarios 1 and 2.

These long-term risk contamination scenarios are, of course, dependent on the quantity of oil that potentially could escape from entrapment in the Weeks Island SPR mine. For each scenario, the oil-leakage quantities were divided into four distinct levels for evaluation, as follows:

Level (1) From significant, detectable levels up to 100 bbl/year * of oil.
Level (2) From 100 to 500 bbl/year * of oil.
Level (3) From greater than 500 to 5000 bbl/year * of oil.
Level (4) From greater than 5000 bbl/year * up to 1.5 MM bbl of oil total.

* Although the oil leakage amounts at each level are listed in terms of barrels/year, potential volumes of oil released should be understood as ***total barrels during the 100-year period***, within the broad ranges given. In this study, environmental risks and impacts were evaluated over a specified 100-year period. This is different, but felt to be more inclusive than, the once in a 1-year, 10-year, 100-year, or 1000-year likelihood(s) of occurrence for leakage discussed in the EA [DOE, 1995]. Actual oil release rates or occurrences could be temporary or intermittent, but they should not be considered constant over the total 100-year period of concern. It is conceivable that the specified volume (ranges) could leak within a single year period. A significant, observable oil-leakage rate and volume would presumably initiate Department of Energy decisions and remediation actions shortly after detection, to minimize further oil release or environmental contamination.

The three specific risk scenarios listed above, plus the four levels of potential oil leakage for each scenario, result in 12 individual risk events for evaluation, i.e., Events 1.1, 1.2, 1.3, 1.4 Events 2.1, 2.2, 2.3, 2.4, and Events 3.1, 3.2, 3.3, 3.4.

For all of the long-term risk events evaluated, the average perceived ***consequence*** of the event ***increased*** significantly as the potential ***volume of oil leakage increased.*** Conversely, the average perceived ***likelihood decreased*** just as significantly ***as the oil volume levels increased.*** In general, the **risk events** with the calculated ***highest average risks*** (expense values) ***are associated with the highest likelihood values -- but with the smallest consequence values.*** For example, the panel members judged a leak level of "detectable and up to 100 bbl/year of oil" as "Likely" for both the "groundwater and sediment contamination, up to 100 bbl" risk (Event 1.1) and the "surface water contamination, up to 100 bbl" risk (Event 2.1). Accordingly, both of these risk events fall within the defined "High" DOE risk category, with an average risk (expense) of $140,000 and $66,000, respectively. Consequence, likelihood, and risk classification *category* labels used are based on a DOE risk coding matrix provided in Appendix C of the EA [DOE, 1995].

There are moderately large calculated uncertainties (specified as one standard deviation) for all determined risks (expenses); these uncertainties are typically a factor of 2X to 3X of the average values. For example, the calculated risk (clean-up and remediation) expenses for risk Event 1.1 ($140,000) are bounded between zero and $370,000; for Event 2.1, the risk (expense) of $66,000 was bounded within a range of zero to $260,000. To a lesser degree, risk Events 1.2

and 1.3 (groundwater and sediment contamination, 100 to 500 bbl for 1.2; 500 to 5000 bbl for 1.3) fall within the "Medium" DOE risk category. Events 1.2 and 1.3 have risks (expenses) of $14,000 (range of $0 to $32,000) and $12,000 (range of $0 to $31,000), respectively. All other potential contamination risks, i.e., Events 1.4, 2.2, 2.3, 2.4, 3.1, 3.2, 3.3, and 3.4, fall within the "Low" DOE risk category, and are approximately a factor of 10 (or more) *smaller* in risk expense magnitude than Events 1.1 and 2.1.

While several of these calculated potential oil clean-up and remediation risk expenses are appreciable, with several falling within the DOE "High" risk category, they must be compared with the projected values (or range of values) of current and planned operational expenses for facility decommissioning. Nominal operational expenses prior to site closure are significantly greater in magnitude.

Generally, environmental impacts defined as "**significant**" in NEPA terminology [DOE, 1995] could result from "High" (category) risk events with the following attributes:

- a high probability of substantially degrading the Gulf Coast environment;
- causing natural resource damage assessments exceeding $100 million;
- causing a spill of oil (or brine) exceeding 2,400 barrels with a high potential for long-term injury to sensitive fish and wildlife habitats, sensitive biologics, or human use activities; or,
- causing public or worker endangerment without adequate warning time.

Based on the defined and calculated long-term environmental risk results presented in this assessment study, including the average likelihoods and potential oil-leakage volumes, **none of the evaluated risk events** would appear to satisfy the definition of **"significant environmental impact"** in NEPA terminology. In summary, the DOE may combine these current results and information with their earlier evaluations and interpretations in the Environmental Assessment [DOE, 1995], in order to assess whether their existing Finding of No Significant Impact (FONSI) [DOE, 1995] is still accurate, acceptable, and valid. However, from a risk evaluation standpoint, the assessment of impacts appears to be the same whether only 10,000 to 30,000 barrels of crude oil (as considered in the 1995 EA) or up to 1.5 million barrels of oil (as considered herein) are abandoned in the Weeks Island SPR facility.

In addition to the multiple environmental contamination risks described, a single defined *short-term* risk event was also evaluated, to support SPR Project considerations. The short-term operational risk of (optionally) delaying mine brine fill in order to skim for more oil was determined to have a "High" average risk. This risk was specifically due to observed, enhanced rates of surface subsidence and consequent impacts on mine instability from being partially empty, in a non-brine-filled condition. Supported by this "High" risk evaluation, the SPR Project initiated mitigation actions, by quickly restarting mine brine filling operations. As a result, the short-term, potential operational risk has been minimized or avoided.

2.0 Risk Assessment Background

Sandia National Laboratories was requested by the Department of Energy SPR PMO to conduct a formal risk assessment study of the current and planned Weeks Island SPR decommissioning program, in support of the DOE Weeks Island Mine Integrity Management Group (WIMIMG). This assessment focuses on possible risk impacts of leaving up to 1.5 million barrels of crude oil in the facility, as part of the decommissioning and abandonment process. This abandoned oil could potentially escape from the mine with consequent long-term environmental contamination risks. Results from this risk assessment study are to provide technical support for upcoming DOE SPR Project evaluations, decisions -- particularly in regards to environmental assessment concerns and the NEPA process, and contingencies.

DOE SPR PMO also requested that this assessment study include and evaluate a single defined *short-term* risk event, the operational risk of (optionally) delaying mine brine fill in order to skim for more oil. This short-term risk has no direct connection to the evaluated long-term environmental risks.

2.1 Participants

This risk assessment evaluation was a joint, interactive effort conducted and compiled by Sandia National Laboratories personnel, with significant input from members of a select panel. Sandia initially developed an extensive list of qualified panel candidates, with DOE Project Management making the actual selections. Sandia's criteria for panel members were that they be knowledgeable in their field, familiar with the Weeks Island geology or operations, technically respected, and independent -- i.e., not directly associated with the DOE SPR Program. Persons selected and able to participate included:

1. Mr. Paul L. Davidson, member Weeks Island Environmental Advisory Committee, Nature Conservancy, environmentalist. Baton Rouge, LA.
2. Dr. Thomas R. Magorian, consulting geologist. Amherst, NY.
3. Professor Edward B. Overton, member Weeks Island Environmental Advisory Committee, Chairman of the Institute of Environmental Studies, Louisiana State University. Baton Rouge, LA.
4. Mr. Charles G. Smith, consulting geologist, familiar with Gulf Coast salt domes and groundwater hydrology. Baton Rouge, LA.
5. Mr. Stewart N. Thompson, Acres International Corp., Vice President. Professional geologist, very familiar with the Weeks Island underground mine. Amherst, NY.
6. Dr. Robert L. Thoms, AGM, Inc., geotechnical consultant. College Station, TX.

2.2 Supporting Information

As part of this study, we briefed the panel members on the following, relevant topics:

- Purpose of the Weeks Island SPR risk assessment meeting, process, and overview details,
- Overview of the Weeks Island mine and layout,
- Current site status and operational, facility, and decommissioning concerns, including site and facility subsidence and mine instabilities,
- Planned plugging and abandonment activities, plus ongoing oil skimming progress and difficulties,
- Oil inventory accounting, reasons and options for abandonment of up to1.5 million barrels of crude oil instead of the originally planned 10,000 to 30,000 bbl,
- Details and major mechanisms for expected long-term oil entrapment and potential release,
- Potential long-term environmental risks from oil leakage and contamination,
- Options for oil skimming and brine fill, and associated operational risks of delaying brine fill to skim for more residual oil,
- Rationale for terminating current oil skimming operations.

Information was provided in the form of extensive view graph presentations, question and answer forums, and interactive discussions between panel members and Sandia National Laboratories and Department of Energy SPR personnel. Panel members were also given a tour of the underground Weeks Island mine (manways), surface facilities and environs, and the two sinkholes, in order to observe relevant geologic or facility details. This information, provided over a period of two half-day sessions, plus the existing expertise in their respective geotechnical fields, provided the bases for the panel members to make valid risk evaluations and judgements.

The overall scope, assumptions, and current supporting information for this risk assessment study are briefly summarized as follows. Up to a maximum of 1.5 million barrels of unrecovered crude oil may be left in the mine after final mine brine-filling, oil skimming, and plugging and abandonment activities at the Weeks Island SPR facility are completed. The upper and lower mine levels plus all other underground workings will be in a brine-filled state. The overall time-frame of concern for risk assessment purposes is up to 100 years following mine decommissioning and abandonment. This is a credible period of time for the Department of Energy or related governmental agency to be concerned with potential oil leakage from the facility and consequent clean-up or remediation expenses for minimizing any significant environmental contamination.

2.2.1 Mechanisms of Oil Entrapment

Multiple mechanisms can be responsible for the long-term entrapment or entombment of residual crude oil in a brine-filled, Weeks Island SPR mine. The most important of these mechanisms are:

a) oil entrapment in the crushed or rubblized salt remaining in the mine, or in existing cracks in mine pillars and surrounding salt,
b) oil entrapment in roof pockets in both the lower and upper mine levels, and
c) oil entrapment in the sediments within the leakage features (sinkholes) and above the mine salt dome. These mined and natural barriers to oil mobility are further enhanced by the geometry of the mine and the man-made bulkhead sys-

tem within the mine, serving to isolate the oil from the environment as part of the long-term storage system.

Crushed salt and salt fines were formed in the mine as a consequence of both the previous (commercial) salt-mining operations and continued spalling of pillars due to salt creep deformation. These fines have been characterized by Acres [Acres American, Inc., 1977] both for grain size and total amount of solids. At the time that the Weeks Island mine was being converted for its use as an SPR oil storage reserve, many piles of salt were left in the mine and additional crushed salt was left on the mine floor. The remaining pores (pore spaces) in this crushed salt were subsequently filled with oil during the about 20 years of oil storage. When the SPR mine was flooded with brine as part of the decommissioning operations, most of this oil remained in the crushed salt, trapped by capillary forces. Oil retention and release experiments performed at Sandia National Laboratories [O'Hern and Hinkebein, 1996] indicated that the amount of this permanently trapped oil in or on salt may vary between 0.8% and 7% of the total mass volume of crushed salt in the mine. Based on current oil accountability data, there could be up to about 1.1 million bbl of oil that remains trapped in the mine in a presumed permanent way by this crushed salt. Furthermore, current measurements of the residual oil thickness floating on the brine in the mine lower level indicate that trapped oil is not noticeably migrating out of the crushed and rubblized salt.

The second barrier to oil mobility is the natural (excavated or blasted) roughness of the mine roof, as well as roof arching or bowing. The mine roof has an appreciable scalloped appearance, with a local relief of about one foot in a one-foot radius, or more. These existing salt pockets in the roof will lead to the formation of physical zones that are expected to trap oil when the mine is fully filled with brine. Each pocket of trapped oil is expected to become isolated since the oil thickness of the residual layer or pool of oil in the mine is approximately 3 inches (expected maximum). Hence, if an individual trapped oil pocket becomes connected to a salt fracture or leak to the outside of the mine, that pocket and possibly a few others surrounding it could drain, buoyed upward by hydrostatic pressures. It is not expected that large quantities of oil will be able to migrate along the roof to the leak because of the significant extent of roof roughness. As a consequence, any individual mine oil leak may lead to the loss of several barrels of oil, but not to significantly large quantities of oil.

The third barrier to oil mobility is the sandy sediment layer(s) present above the top of the salt dome and in the sinkholes. Naturally occurring sediment mineral fines will retain oil by capillary forces. Small amounts of oil become trapped in the sediments and do not move [Bear, 1975]. It is only when a critical value of the oil saturation is exceeded that any oil movement will occur. This effect is a primary limiting phenomenon in the production of oil from oil sands. Because of this effect, recovery of oil by water flooding techniques seldom reduces the residual oil to less than 20% of the total pore volume [Bradley, 1992]. It is only when a sufficient quantity of oil is available that any motion can occur. It is known also that the leaking sinkholes above the Weeks Island mine are filled with sand from the Alton sand and gravel layers above the top of the salt dome. These sediments have the potential to retard the movement of oil away from the mine.

2.2.2 Mechanisms of Oil Escape

Some of the entrapped, residual oil in the Weeks Island mine could possibly escape during the 100-year time period of concern. Escape could be through either natural pathways in the salt (sink holes, salt fractures, salt dilatancy, etc.) or through compromised, man-made pathways (sealed shafts, fill holes, brine pressure-relief pathways, monitoring wells, etc.). Larger volumes of oil escaping as a liquid, as well as smaller amounts of dissolved oil (hydrocarbon components dissolved in brine or groundwater, at parts-per-million concentrations) must be considered as sources of potentially significant environmental contaminants.

At the present time, there are two naturally occurring sinkholes and one drainage feature associated with the Markel Wet Drift that connects with the underground. Only one of the sink-holes (Sinkhole #1) is known to connect to the oil storage horizons within the Weeks Island mine. In addition to these natural connections, these are also two shafts (the Service shaft and the Production shaft), two fill holes, and a vent hole that connect to the surface. There are also two raise bores and the Markel Incline (all with plugs or bulkheads installed) that connect the mine to the overlying manways; the manways connect to the two shafts. Any of these connections could become a potential leakage path to expose oil to the environment. While we do not expect that large quantities of oil will travel along these paths, they are representative of credible man-made leakage paths.

As part of the Weeks Island SPR decommissioning process, it is planned to plug and seal all manmade features *except* for the East fill hole. The natural salt creep closure of the mine will lead to the expulsion of 5,000 – 8,000 bbl/year of brine from the mine via this pathway. The bottom of the fill hole casing is located in the bottom of the lower mine level. This location helps ensure that any oil floating on the top of the brine, trapped near the mine roof, will not directly exit via the fill hole pathway. It is planned that brine will be discharged through intentional per-forations of the existing casing in the East fill hole. These perforations are to be placed at the top of the salt so that brine discharge (at hydrostatic pressure) will be to the natural brine fluid layer residing at the top of the salt dome. Because this fluid is already salt saturated, the additional brine discharge will have minimal effect on the local salinity. It is also recognized that oil has a limited solubility in brine (~100 mg/l, ~100 parts-per-million). If the brine discharged from the mine were fully saturated with oil hydrocarbons, then the total oil loss through this mechanism would be about 1 bbl/year.

The total amount of oil available that could escape from a single leakage path from the mine roof may be estimated from an assumption of the number of roof pockets that are con-nected to the leak. To determine the magnitude of the source term for a single leak, consider the following basis. Suppose that a 100 ft^2 area of roof is assumed to be connected and also to drain through a single leakage pathway, and the oil thickness is assumed to be equal to the current pooled oil thickness in the mine, about 3 inches. For this case, the source term for that individual leak would be 4 to 5 bbl of oil. The leakage scenario would be that this 4 - 5 bbl of oil could leak through the sinkhole to the groundwater above the top of salt.

If sealed mine bulkheads are considered as a source of oil escape, the leakage path would be somewhat longer. In this case, trapped oil may leak past the bulkhead and rise to the water table elevation on the inside of the shaft. With time, cracks in the mine shaft liner may allow this oil to escape into the groundwater.

One additional pathway considered in this study is the leakage of oil from the Weeks Island SPR mine directly to the nearby Morton Salt mine. In this scenario, the closest approach to the Morton mine is through the salt between the underground Mulkey drift and the Morton shafts. While the total amount of salt is not large for this pathway (about 43-foot thickness, minimum), it is planned to fill both the Mulkey drift and the Markel mine with brine. The Mulkey drift goes downhill from the Weeks Island mine manways to the Markel mine. For this scenario, the oil leakage pathway would be from the Weeks Island mine to the manways above, and then against the hydraulic gradient to the Mulkey drift. Because the movement of oil in a brine-filled mine will always be upward, this pathway will only be functional if a large leak is not repaired. The leakage of oil through hundreds of feet of intact salt or even dilatant (slightly fractured) salt is not considered reasonable or significant.

Assuming oil makes its way to the groundwater, dispersal of this oil is expected to occur by natural rainfall-induced movement of the groundwater. The Weeks Island salt dome is located in an area where the water table is essentially at sea level, with little spatial variation in the piezometric head. Further, surface water flow has been noted to be radial off of the dome [Acres International, 1987]. As a consequence, the natural dispersal will result from the normal rainfall that will cause movement of groundwater off of the dome, also in a near radial manner.

One additional consideration to potential environmental impacts for released oil is the weathering of oil once is gets into the environment. Oil will naturally fractionate in the groundwater environment, so that the lighter weight and more mobile components of the crude oil will separate from the heavier oil components. This natural action will leave the heavier, residual components less mobile. These heavier residual oil components may eventually form non-mobile tar balls. In addition, the oil (particularly the lighter components) in the groundwater, or potentially floating as a sheen on surface waters, should also be considered to be subject to eventual biological attack, i.e., to microbial bioremediation actions. This bioremediation would serve to minimize the concentration of escaped oil (both as a liquid or dissolved), thereby minimizing the degree of potential environmental contamination and consequent impacts.

Oil contamination that may eventually be found in the surface waters near the Weeks Island facility can originate from sources other than the SPR mine. Other potential contaminant sources include: other oil reserves within or at the edge of the salt dome that are presently being exploited; oil discharges off the Louisiana coast from commercial ships, tankers, barges or offshore facilities (these other sources were discussed in the DOE EA [DOE, 1995]); illegal dumping of used motor oils, etc. To assist in differentiating the potential source of contamination, the DOE SPR Project recently initiated a laboratory program to chemically characterize, i.e., fingerprint, the likely source of the oil. Reference samples of Weeks Island oil have been archived for later identity characterizations. Of primary SPR Project concern is having the ability to identify Weeks Island SPR crude oil (for legal responsibility determinations), as specifically distinct from other sources, when only a small amount of weathered oil contaminant is available for testing.

2.2.3 Mechanisms Contributing to Short-Term Operational Risk

A number of operational difficulties were encountered during the skimming of oil at the lower level of the Weeks Island mine. The design skimming rate was to have been 21,000 bbl/day. In the course of filling the mine with brine to the design skimming location, the mine was overfilled with brine, so that oil layer became inaccessible at the service shaft location. Several months were required to remove the excess brine overfill amount. As a consequence of the brine overfill and the slow rate of brine withdrawal, the connection between the service shaft skimming location and the rest of the mine was minimal.

Once the oil skimming operations recommenced, it was observed that a tight emulsion between the oil and brine was produced. This emulsion required the addition of emulsion breaking chemicals to assist in the separation of the oil from the brine. This operation initially slowed the skimming rate until the proper combination of water addition and emulsion breaker could be determined.

Finally, further skimming operations were severely impeded by mine trash build-up on the screens at the entrance to the service shaft. This trash build-up was so severe that the oil thickness in the service shaft was less than 0.5 inch while the oil thickness in the mine was 3.5 inches. Further, the oil rebound rate in the service shaft was in excess of several days. This combination of effects caused the maximum obtainable oil-skimming rate to decrease to less than 500 bbl/day. As a result, the operational expense for removing a barrel of oil by skimming was several times greater than the actual cost of the oil. The cost effective basis for this operation was lost while the operational difficulty for continuing increased significantly.

During the same time period for skimming, the subsidence rate observed at the surface over the top of the mine was dramatically increasing [Bauer, 1999]. This increase was observed to vary from near 0 in/year at the edge of the mine to ~ 12 in/year over the mine centroid.

3.0 Risk Scenarios

The specific *pathways* for oil leakage and escape from the mine (described in Section 2) are not the principal concern for potential risk from environmental contamination. Most importantly, the specific risk scenarios evaluated result from *significant, detectable oil leakage from all pathways combined* and potential consequent long-term environmental contamination or impact to three locales. The risk scenarios and locales are as follows:

Scenario 1. **Potential long-term (within 100 years) environmental contamination of groundwater and sediments above the Weeks Island salt dome due to oil leakage.** Any significant oil leakage could be detected and quantified in any of the numerous monitoring wells, or elsewhere, on the Weeks Island site.

Scenario 2. **Potential long-term (within 100 years) environmental contamination of the surface waters surrounding the Weeks Island site, into Weeks or Vermilion Bay.** Any significant oil leakage could potentially migrate from or through the groundwater and sediments to the adjacent surface waters, and would be observable as an oil sheen or slick.

Scenario 3. **Potential oil leakage from the Weeks Island mine into the Morton Salt Mine, following its eventual abandonment, with subsequent long-term environmental contamination.** During the commercial Morton Salt Mine's operating lifetime (possibly for another 25 years or longer), small amounts of oil seeping into this mine would be an economic, not an environmental, concern. As such, it will not be considered as part of this environmental risk assessment study. However, following the Morton Salt Mine closure and abandonment, conceivable oil leakage into the Morton Mine through geologic and groundwater plus sediment pathways would not be readily observable. This scenario could contribute to eventual long-term environmental contamination of the adjacent groundwater and sediment, surface waters, and salt, as in the above scenarios. This is the risk to be assessed.

All of these potential contamination scenarios are dependent, of course, on the *quantity* of uncontrolled oil leakage, oil escaping from entombment in the Weeks Island mine. These oil-leakage quantities and/or rates can be categorized into five distinct *levels*, as follow:

Level (0) From zero leakage to below detectable levels. This is the initial anticipated base case, with essentially *no or insignificant oil leakage* and *no contamination of the accessible environment*. The consequence of this base case, insignificant leakage is ZERO; there is, therefore, no risk to the SPR *and no further evaluation* of this level.

Level (1) From significant, detectable levels up to 100 bbl/year * of oil.

Level (2) From 100 to 500 bbl/year * of oil.

Level (3) From greater than 500 to 5000 bbl/year * of oil.

Level (4) From greater than 5000 bbl/year * up to 1.5 million bbl of oil total.

* Although the oil leakage amounts at each level are listed in terms of barrels/year, potential volumes of oil released should be understood as ***total barrels during the 100-year period***, within the broad ranges given. In this study, environmental risks and impacts were evaluated over a specified 100-year period. This is different, but felt to be more inclusive than, the once in a 1-year, 10-year, 100-year, or 1000-year likelihood(s) of occurrence for leakage discussed in the DOE EA (DOE, 1995) for the Weeks Island facility. Actual oil release rates or occurrences of could be temporary or intermittent, but they should not be considered constant over the total 100-year period of concern. It is conceivable that the specified volume (ranges) could leak within a single year period. A significant, observable oil-leakage rate and volume would presumably initiate Department of Energy decisions and remediation actions shortly after detection, to minimize further oil release or environmental contamination.

The total volume of oil escaping must be both observable and measurable to be significant. If the volume of oil is dispersed over a large area (or volume) of sediment and groundwater, in a semi-homogeneous manner, it probably will not be observable or barely detectable (e.g., at parts-per-million levels). Such a volume could be categorized in Level (0), above.

The likelihood or probability of oil leakage in the range of non-detectable up to 1.5 million (MM) bbl total within 100 years from all five defined levels must equal 1.00 (1 in 1 chance, 100%). However, it is anticipated that the vast majority of residual, entrapped oil will never escape from the Weeks Island mine, i.e., at described Level (0). Therefore, the combined probabilities from Levels (1), (2), (3), and (4), above, should be significantly below 1.00 in total.

3.1 Specific Risk Events

With the three defined locales of potential long-term environmental oil contamination and four significant levels of oil leakage, we can now define the overall risk scenarios, or risk events to be assessed:

Scenario 1. Potential long-term (within 100 years) environmental contamination of groundwater and sediments above the Weeks Island salt dome due to oil leakage, in the amounts of:

Event 1.1 From significant, detectable levels up to 100 bbl/year of oil.
Event 1.2 From 100 to 500 bbl/year of oil.
Event 1.3 From >500 to 5000 bbl/year of oil.
Event 1.4 From >5000 bbl/year up to 1.5 MM bbl of oil total.

Scenario 2. Potential long-term (within 100 years) environmental contamination of the surface waters surrounding the Weeks Island site, into Weeks or Vermilion Bay, due to oil leakage in the amounts of:

Event 2.1 From significant, detectable levels up to 100 bbl/year of oil.
Event 2.2 From 100 to 500 bbl/year of oil.
Event 2.3 From >500 to 5000 bbl/year of oil.
Event 2.4 From >5000 bbl/year up to 1.5 MM bbl of oil total.

Scenario 3. Potential oil leakage from the Weeks Island mine into the Morton Salt Mine, following its eventual abandonment, with subsequent long-term (within 100 years) environmental contamination, from oil in the amounts of:

Event 3.1 From significant, detectable levels up to 100 bbl/year of oil.
Event 3.2 From 100 to 500 bbl/year of oil.
Event 3.3 From >500 to 5000 bbl/year of oil.
Event 3.4 From >5000 bbl/year up to 1.5 MM bbl of oil total.

Based on concerns of recently observed, accelerated site subsidence that potentially affects the stability of the Weeks Island mine, shafts, and surface facilities, the DOE SPR requested that this study also consider operational options related to the decommissioning process at the facility. The DOE SPR Project Management Office therefore requested that one *short-term* risk event also be assessed in this study, defined as follows.

Event 4 The potential short-term operational risk from (the option of) delaying mine brine fill in order to skim more oil.

This short-term risk has no direct connection to the long-term environmental risks, above. Evaluated risk values from this short-term risk event could help the DOE resolve and support decisions to proceed with several decommissioning operational options. These options include continuing forward with ongoing oil skimming operations to recover more oil, or concluding the skimming operation and resume mine brine filling, to more quickly enhance mine stability.

3.2 Risk Assessment Process Details

Following the risk assessment panel meeting briefings, information transfer, interactive discussions, and mine and facility tour, we solicited quantifiable input from each panel member. This input, submitted anonymously, consisted primarily of their informed but subjective (semi-quantitative, order-of-magnitude) estimates on:

a) consequence (severity) for each defined risk scenario or event, above, and,
b) likelihood (probability) for each potential risk event, e.g., environmental contamination or operational risk, should it occur.

The magnitude or extent for both consequences and probabilities is detailed below.

3.2.1 Risk Definition

The potential risk of a specific risk event, R_i, is defined and can be calculated as the product of the consequence of that event, Ci , times its likelihood of occurrence, Pi :

$$R_i = C_i \times P_i$$

The method of evaluating risk (magnitude) by obtaining subjective input and evaluation of consequence and likelihood from knowledgeable panel members is termed the "Delphi" method. It is quite useful for providing semi-quantitative risk evaluations and rank ordering of the relative risks in a group of risk events. The Delphi method [Linstone and Turoff, 1975] sometimes uses iterative solicitations of input from a group of usually *anonymous* experts to move toward a consensus. In this study, the Delphi method was modified or restricted somewhat in that only a single solicitation for input was used; this was due to a limited time period available for overall study definition, preparation, solicitation, calculations, interpretations, and reporting. This methodology also has some acknowledged limitations in that the semi-quantitative results obtained have the potential to be more indicative of perceptions of identified problems rather than being highly detailed or definitive in nature. These limitations were explained to, and accepted by the panel members and the DOE SPR Project Management Office. Nonetheless, this methodology, when supported by as much relevant information on the risk scenarios as possible, can provide useful, defensible, and referenceable results. The risk assessment results may then be used to guide or support future SPR Project decisions, particularly as related to risk minimization and regulatory compliance-environmental assessment issues.

3.2.2 Probability Evaluations

The panel members (listed in Section 2.1) individually evaluated the probability (Pi) or likelihood of occurrence for each specified risk event, should it occur. They used their best judgment, based on information both already known and presented to them, without performing detailed analyses. Their evaluations were in terms of the following "likelihood levels" or ranges, listed in Table 1. These likelihood "order-of-magnitude" levels are specifically semi-quantitative estimates, to be used for relative ranking purposes. (Note: Numerical *level* ranges presented in Tables 1 and 2 should not be confused with "oil volume" *levels* already used to define the risk events). Level ranges number 6 through 1 are each a factor of ten greater than the next lower level. Levels are rank-ordered from "Highly Likely" to "Extremely Unlikely." The likelihood level "names" in Table 1, e.g., "Likely" or "Possible," are intended to parallel "probability category" designations in a DOE SPR Risk Coding Matrix [in Appendix C, DOE, 1995], as adapted from an Environmental Safety and Health Management Plan. The "Very Unlikely" and "Extremely Unlikely" categories were added for use in this current study. The likelihood levels in Table 1 refer to the probability of a defined risk event occurring at least once, possibly several times, during the 100-year period of concern following the Weeks Island SPR facility decommissioning and abandonment; they are *not* potential yearly frequencies.

Table 1. Likelihood (Probability) Levels, P

• **Level 6**	**"Highly Likely"**	(**~ 1.0**)	(about 1 in 1 chance, 100%)
• **Level 5**	**"Likely"**	(**0.1**- 0.01)	(about 1 in 10 chance, 10%)
• **Level 4**	**"Possible"**	(**0.01**- 0.001)	(about 1 in 100 chance, 1%)
• **Level 3**	**"Unlikely"**	(**0.001**- 0.0001)	(about 1 in 1,000 chance, 0.1%)
• **Level 2**	**"Very Unlikely"**	(**0.0001**- 0.00001)	(about 1 in 10,000 chance, 0.01%)
• **Level 1**	**"Extremely Unlikely"**	(**≤ 0.00001**)	(about 1 in a 100,000 chance, 0.001%)

(For purposes of risk calculation, the highest value in the specified range for each likelihood level, in **bold** numbers, is used, e.g., for "Unlikely," P = 0.001)

3.2.3 Consequence Evaluations

If a defined, long-term environmental or short-term operational risk event occurred, it would have specific consequences. Primary consequences can be expressed in terms of:

a) oil leakage clean-up costs, dependent on the volume and rate of oil leakage;
b) facility remediation expenses, to minimize or stop further leakage; and,
c) possible health and safety impacts from hazardous oil components, with the potential for injury to sensitive fish and wildlife habitats, sensitive biologics, or human-use activities. The term "environmental injury" is as defined in 59FR34098 (July 1, 1994); "sensitive environments" are defined in 59FR14713 (March 29, 1994), and are expanded to include human use of groundwater [DOE, 1995].

Consequences resulting from potential legal or regulatory compliance expenses are not specifically considered nor included in this assessment study because they are beyond the direct control of the SPR Program and cannot be credibly estimated. Possible health and safety impacts are considered to fall within the "legal or regulatory compliance" categorization for estimation of expenses. Therefore, for this risk assessment study, consequences are specifically stated in terms of oil clean-up and facility remediation expenses, only.

In order to provide some common basis for consequence comparison, each type of consequence can be translated into some relative severity level (range) of financial loss or expense to the Department of Energy SPR Program, or a successor governmental agency. This type of financial translation was done in an earlier 1984 Weeks Island risk assessment study for continued safe operations [Beasley, et al., 1985], and again is used for this study.

In a manner similar to the ranking of likelihoods in Table 1, the risk assessment panel members were requested to individually evaluate the potential consequence (Ci) of each specified risk event, should it occur, using their best judgment, without performing detailed analyses. Evaluations are in terms of the following broad consequence (severity) levels, listed in Table 2. These levels are also rank ordered from a credible maximum, "Catastrophic ++" level to minimal or "Negligible" level, all expressed in terms of dollar expense.

Table 2. Consequence (Severity) Levels, C
(Clean-up and facility remediation expenses, only)

- **Level 6 "Catastrophic ++"** up to **$1 Billion**
- **Level 5 "Catastrophic +"** up to **$100 Million**
- **Level 4 "Catastrophic"** up to **$10 Million**
- **Level 3 "Critical"** up to **$1 Million**
- **Level 2 "Marginal"** up to **$100,000**
- **Level 1 "Negligible"** ≤ **$10,000**

(Only the maximum dollar value in each stepwise range listed is shown; this is the value used in subsequent risk calculations.)

The consequence level "names" in Table 2, e.g., "Critical" or "Marginal," are adapted from, and are intended to parallel "severity category" designations in a DOE SPR Risk Coding Matrix [in Appendix C, DOE, 1995]. Table 3 provides the complete, *extrapolated* risk assessment coding matrix used in the current risk evaluation study. Table 3 lists all of the consequence levels, likelihood levels, the dollar values for (calculated) risk expenses, and the risk “name” categories.

This 1995 DOE risk coding matrix also listed a quantity of spilled oil for the environmental consequences of each severity level. For example:

- "Catastrophic” (Level 4) includes spills of greater than ~2400 bbl of oil;
- “Critical” (Level 3) includes spills of ~240 to 2400 bbl;
- “Marginal” (Level 2) includes spills of less than ~240 bbl, and
- “Negligible” (Level 1) specifies non-reportable spill levels.

These oil spill sizes are those defined for coastal regions in the DOE National Spill Contingency Plan [as referenced in Appendix C, DOE, 1995]. For purposes of the current risk assessment study, the "Catastrophic ++" and "Catastrophic +" levels were added, in order to include potentially greater clean-up and remediation expenses, as well as larger volumes of oil leakage. These “consequence” oil spill volumes are also shown in Table 3, for completeness.

Table 3. Extrapolated Risk Assessment Coding Matrix
(as used in 1998 Weeks Island SPR risk assessment study)

Overall RISKS - $ Expenses						
CONSEQUENCE (Severity) ↓	**LIKELIHOOD:** (Probability) →					
[oil spill volumes, from 1995 EA]	**HIGHLY LIKELY (~ 1.0)**	**LIKELY** (**0.1** - 1.0)	**POSSIBLE** (**0.01** - 0.10)	**UNLIKELY** (**0.001** - 0.01)	**Very Unlikely** (**0.0001** - 0.001)	**Extremely Unlikely** (**≤ 0.00001**)
Catastrophic ++ ($100 M - **$1 B**)	**Very High Risk** ($1 B)	**Very High Risk** ($100 M)	**High Risk** ($10 M)	**High Risk** ($1.0 M)	Medium Risk ($100 K)	Low Risk ($10 K)
Catastrophic + ($10 - **$100 M**)	**Very High Risk** ($100 M)	**High Risk** ($10 M)	**High Risk** ($1.0 M)	Medium Risk ($100 K)	Low Risk ($10 K)	Low Risk ($1 K)
Catastrophic ($1.0 - **$10 M**) [> 2400 bbl]	**High Risk** ($10 M)	**High Risk** ($1.0 M)	**High Risk** ($100 K)	Low Risk ($10 K)	Low Risk ($1 K)	Very Low Risk ($100)
Critical ($100K - **$1.0 M**) [240 - 2400 bbl]	**High Risk** ($1.0 M)	**High Risk** ($100 K)	Medium Risk ($10 K)	Low Risk ($1 K)	Very Low Risk ($100)	
Marginal ($10K - **$100K**) [< 240 bbl]	Medium Risk ($100 K)	Medium Risk ($10 K)	Low Risk ($1 K)	Very Low Risk ($100)		
Negligible (< **$10K**) [non-reportable]	Low Risk ($10 K)	Low Risk ($1 K)	Very Low Risk ($100)			

(Extrapolated categories or levels, not in the 1995 DOE risk coding matrix, are shown in heavy-line cell boxes.)

(**Bold** values in Consequence and Likelihood value ranges used for calculation of risk, $R_i = C_i \times P_i$)

4.0 Risk Assessment Results and Discussion

All evaluations of long-term environmental risk event potential likelihoods (P_i) and consequences (C_i) that were received from the panel members have been compiled and processed, and are summarized in Tables 4, 5, and 6. The calculated risk results ($\mathbf{R_i = C_i \times P_i}$) are also presented in these tables.

The values presented are average values ± uncertainties; uncertainties were calculated and are specified as one standard deviation. For risk values, both the average ± uncertainties and the total range in values are shown. (Obviously, the lower range of the calculated values, i.e., minus the standard deviation, is zero.) One should note the moderately large calculated uncertainties for these risk expenses, typically a factor of 2X to 3X of the average values. Because of the broad ranges used for consequence and likelihood evaluation (refer to Tables 1 and 2) by the risk assessment panel members, and the extent of the calculated uncertainties, all values presented in Tables 4, 5, and 6 are limited to two significant figures.

Table 4. Potential Long-Term (within 100 years) Environmental Contamination of the Groundwater and Sediments above Weeks Island Salt Dome

RISK Event	Average CONSEQUENCE (DOE Severity Category)	Average LIKELIHOOD (DOE Probability Category)	Average RISK [Risk, range] (Clean-up & Remediation Costs) (DOE Risk Category)
1.1 (detectable up to 100 bbl/yr of oil)	\$390,000 ± \$480,000 (Critical)	37% ± 49% (Likely)	**\$140,000 ± \$230,000** [\$0 - \$370,000] (High)
1.2 (from 100 to 500 bbl/yr of oil)	\$700,000 ± \$460,000 (Critical)	2.0% ± 3.9% (Possible)	**\$14,000 ± \$18,000** [\$0 - \$32,000] (Medium)
1.3 (from >500 to 5000 bbl/yr of oil)	\$7,000,000 ± \$4,600,000 (Catastrophic)	0.17% ± 0.41% (Unlikely)	**\$12,000 ± \$19,000** [\$0 - \$31,000] (Medium)
1.4 (from >5000 bbl/yr to ≤ 1.5 MM bbl total)	\$55,000,000 ± \$49,300,000 (Catastrophic+)	0.018% ± 0.040% (Very Unlikely)	**\$9,600 ± \$20,000** [\$0 - \$30,000] (Low)
1. TOTAL			**\$180,000 ± \$230,000** [\$0 - \$410,000]

In a brief summarization of all of the long-term risk scenarios, the average perceived ***consequence*** of the events ***increased*** significantly as the potential ***volume of oil leakage increased.*** However, the average perceived ***likelihood decreased*** just as significantly ***as the volume levels increased.*** In general, the risk events with the calculated ***highest average risks*** (expense values) ***are associated with the highest likelihood values -- but with the smallest consequence values.***

Table 5. Potential Long-Term (within 100 years) Environmental Contamination of the Surface Waters in Weeks or Vermilion Bay			
RISK Event:	Average CONSEQUENCE (DOE Severity Category)	Average LIKELIHOOD (DOE Probability Category)	Average RISK [Risk, range] (Clean-up & Remediation Costs) (DOE Risk Category)
2.1 (detectable up to 100 bbl/yr of oil)	$390,000 ± $480,000 (Critical)	17% ± 41% (Likely)	**$66,000 ± $190,000** [$0 - $260,000] (High)
2.2 (from 100 to 500 bbl/yr of oil)	$2,100,000 ± $3,900,000 (Catastrophic)	0.22% ± 0.38% (Unlikely)	**$4,500 ± $15,000** [$0 - $20,000] (Low)
2.3 (from >500 to 5000 bbl/yr of oil)	$22,000,000 ± $38,000,000 (Catastrophic+)	0.024% ± 0.038% (Very Unlikely)	**$5,200 ± $14,000** [$0 - $20,000] (Low)
2.4 (from >5000 bbl/yr to ≤ 1.5 MM bbl total)	$390,000,000 ± $480,000,000 (Catastrophic++)	0.001% ± 0.000% (Extremely Unlikely)	**$3,900 ± $0** [$0 - $3,900] (Low)
2. TOTAL			**$80,000 ± $190,000** [$0 - $270,000]

Table 6. Potential Oil Leakage from Weeks Island into the Morton Salt Mine With Subsequent Long-Term (within 100 years) Environmental Contamination			
RISK Event:	Average CONSEQUENCE (DOE Severity Category)	Average LIKELIHOOD (DOE Probability Category)	Average RISK [Risk, range] (Clean-up & Remediation Costs) (DOE Risk Category)
3.1 (detectable up to 100 bbl/yr of oil)	$220,000 ± $380,000 (Critical)	0.21% ± 0.39% (Unlikely)	**$450 ± $1,500** [$0 - $2,000] (Low)
3.2 (from 100 to 500 bbl/yr of oil)	$2,100,000 ± $3,900,000 (Catastrophic)	0.04% ± 0.05% (Very Unlikely)	**$760 ± $1,900** [$0 - $2,700] (Low)
3.3 (from >500 to 5000 bbl/yr of oil)	$4,000,000 ± $4,600,000 (Catastrophic)	0.021% ± 0.039% (Very Unlikely)	**$820 ± $1,800** [$0 - $2,600] (Low)
3.4 (from >5000 bbl/yr to ≤ 1.5 MM bbl total)	$55,000,000 ± $49,000,000 (Catastrophic+)	0.004% ± 0.005% (Extremely Unlikely)	**$2,200 ± $2,300** [$0 - $4,500] (Low)
3. TOTAL			**$4,200 ± $3,800** [$0 - $8,000]

For example, the panel members judged a leak level of "detectable and up to 100 bbl/year of oil" as "Likely" for both the "groundwater and sediment contamination, up to 100 bbl" risk (Event 1.1, Table 4) and the "surface water contamination, up to 100 bbl" risk (Event 2.1, Table

5). Accordingly, both of these risk events fall within the defined "High" DOE risk category, with an average risk (expense) of $140,000 and $66,000, respectively.

The calculated risk (clean-up and remediation) expenses for Event 1.1 ($140,000) are bounded between zero and $370,000; for Event 2.1, the risk of $66,000 was bounded within a range of zero to $260,000. To a lesser degree, Risk events 1.2 and 1.3 (groundwater and sediment contamination, 100 to 500 bbl for 1.2; 500 to 5000 bbl for 1.3) fall within the "Medium" DOE risk category. Events 1.2 and 1.3 have risks of $14,000 (range of $0 to $32,000) and $12,000 (range of $0 to $31,000), respectively. All other potential long-term contamination risks, i.e., Events 1.4, 2.2, 2.3, 2.4, 3.1, 3.2, 3.3, and 3.4, fall within the "Low" DOE risk category, and are approximately a factor of 10 (or more) *smaller* in risk expense magnitude than risk Events 1.1 and 2.1.

Table 7 summarizes the average risk results listed in Tables 4, 5, and 6 and also includes a column labeled "Average Volume" of oil leakage. The "Average Volume" is a expression of the probability that the listed volume will escape the mine over the total 100-year period of concern. This "Average Volume" is calculated simply as the product of "*Average Likelihood*" values (in Tables 4, 5, and 6) *multiplied* by the *upper volume of oil* in the volume range, e.g., 5,000 bbl of oil for (the >500 to 5,000 range in) Risk Event 1.3. There is some question, however, if this calculated volume has some valid use -- compared to the specified volume ranges for each risk event definition. For risk Events 1.1, 1.2, 1.3, and 2.1, the oil leakage "Average Volumes" can be categorized as "marginal," (refer to the Consequence column in Table 3), all are less than ~240 bbl of oil. Similarly, for risk Events 2.2, 2.3, 3.1, 3.2, and 3.3 the oil leakage volumes can be categorized as "negligible," and all are in the range of about 1 bbl or less of oil. The average volumes of oil leakage for risk events 1.4, 2.4, and 3.4 are listed within parentheses in Table 8 because they are based on the maximum volume of oil specified for the risk scenarios, "up to 1.5 MM bbl total;" as such, these numbers are probably quite inflated. The largest calculated volume, 270 ± 600 bbl for Event 1.4, might place it in the "critical" category. However, based on the "very unlikely" likelihood of occurrence (refer to Table 1) for a spill of this magnitude, this oil leakage average volume is specified as "negligible-critical."

The assessed environmental consequences for oil leakage volumes should be considered as dependent on *where* the leaked oil may be detected, in what *quantities*, and what its future *impacts* or *consequences* on the local environment are evaluated to be. For example, presume that an oil volume of 100 bbl escapes from entombment in the Weeks Island mine and is located (detected) solely at the top of a sinkhole. The clean-up consequences (expense) for this contamination event, as well as the urgency for remediation, may indeed be of the extent specified in Table 7 for risk Event 1.1, within the range of $0 to $370,000. However, if the same volume of oil is dispersed over, say, 1 acre of groundwater and sediment above the salt dome, its "visibility" may be significantly less, its detection level may be at the multi-parts-per-million concentration level, and the need or urgency for remediation may be minimal. The significance of this type of dispersed oil leakage, i.e., the impact as determined under environmental assessment considerations, would be appreciably less. Conversely, if the same 100 bbl of leaked oil is found in surface waters, e.g., floating on the nearby Intercoastal Waterway or Vermilion Bay, evaluated environmental consequences, clean-up expenses, and urgency would be significant, probably at the upper end of the listed range for risk Event 2.1, $0 to $260,000. As shown in Table 7, the potential

Table 7. Summary of Calculated Average Risks and Oil Leakage Volumes

Long-Term Environmental Contamination Risk Events:	**Average RISK** (DOE Risk Category)	**Average Volume of Oil Leakage** (maximum ranges, within 100 years)
Potential Contamination of the Weeks Island Groundwater and Sediments, from Oil Volume of:		
1.1 Detectable levels up to 100 bbl/yr	**$140,000 ± $230,000 (High)**	**37 ± 49 bbl** (marginal)
1.2 From 100 to 500 bbl/yr	**$14,000 ± $18,000** (Medium)	**10 ± 20 bbl** (marginal)
1.3 From >500 to 5000 bbl/yr	**$12,000 ± $19,000** (Medium)	**9 ± 21 bbl** (marginal)
1.4 From >5000 bbl/yr up to 1.5 MM bbl total	**$9,600 ± $20,000** (Low)	(270 ± 600 bbl) (negligible-critical)
Potential Contamination of the Surface Waters in Weeks or Vermilion Bay, from Oil Volume of:		
2.1 Detectable levels up to 100 bbl/yr	**$66,000 ± $190,000 (High)**	**17 ± 41 bbl** (marginal)
2.2 From 100 to 500 bbl/yr	**$4,500 ± $15,000** (Low)	**1 ± 2 bbl** (negligible)
2.3 From >500 to 5000 bbl/yr	**$5,200 ± $14,000** (Low)	**1 ± 2 bbl** (negligible)
2.4 From >5000 bbl/yr up to 1.5 MM bbl total	**$3,900 ± $0** (Low)	(15 ± 0 bbl) (negligible-critical)
Potential Consequences from Oil Leakage into the Morton Salt Mine, from Oil Volume of:		
3.1 Detectable levels up to 100 bbl/yr	**$450 ± $1,500** (Low)	**0.2 ± 0.4 bbl** (negligible)
3.2 From 100 to 500 bbl/yr	**$760 ± $1,900** (Low)	**0.2 ± 0.3 bbl** (negligible)
3.3 From >500 to 5000 bbl/yr	**$820 ± $1,800** (Low)	**1 ± 2 bbl** (negligible)
3.4 From >5000 bbl/yr up to 1.5 MM bbl total	$2,200 ± $2,300 (Low)	(60 ± 80 bbl) (negligible-critical)

consequences from any oil leakage from the Weeks Island mine into the Morton Salt Mine, and subsequent long-term environmental contamination, appears to be negligible.

The calculated risk values from this risk assessment study must be considered as a guide only, for future DOE SPR Project evaluations, decisions, or actions. A significant, observable oil-leakage rate and volume from the Weeks Island mine would presumably initiate Department of Energy SPR Project (or successor governmental agency) decisions and remediation actions when and if such contamination occurs, in order to minimize further oil release or environmental contamination.

While several of the calculated potential risk expenses are appreciable, with several falling within the DOE "High" risk category, they must be compared with the projected values (or range of values) of current and planned operational expenses for facility decommissioning. Nominal operational expenses prior to site closure are significantly greater in magnitude, e.g., in the \$100,000 to \$Million range.

Generally, environmental impacts defined as "**significant**" in National Environmental Policy Act, NEPA, terminology (DOE, 1995) could result from "High" (category) risk events with the following attributes:

- a high probability of substantially degrading the Gulf Coast environment;
- causing natural resource damage assessments exceeding \$100 million;
- causing a spill of oil (or brine) exceeding 2,400 barrels with a high potential for long-term injury to sensitive fish and wildlife habitats, sensitive biologics, or human use activities; or,
- causing public or worker endangerment without adequate warning time.

Based on the defined and calculated long-term environmental risk results presented in this risk assessment study, including the calculated average likelihoods of oil release and potential oil-leakage volumes, **none of the evaluated risk events** would appear to satisfy the definition of **"significant environmental impact"** in NEPA terminology. The DOE may combine these current results and information with their earlier evaluations and interpretations in the Environmental Assessment (DOE, 1995) in order to assess whether their existing Finding of No Significant Impact (FONSI) (DOE, 1995) is still accurate, acceptable, and valid. However, from a risk evaluation standpoint, the assessment of impacts appears to be the same whether only 10,000 to 30,000 barrels of crude oil (as considered in the 1995 EA), or up to 1.5 million barrels of oil (as considered herein) are abandoned in the Weeks Island SPR facility.

In addition to the multiple long-term, potential environmental contamination risks described, a single defined **short-term** risk event, the operational risk of (optionally) delaying mine brine fill in order to skim for more oil, was evaluated to help support SPR Project considerations. Calculated risk results for this short-term event are presented in Table 8. This short-term operational risk was evaluated to have a "Catastrophic+" average consequence, a "Likely" probability of occurrence, and a resultant "High" average risk of \$17,000,000 ± \$18,000,000.

Although the purpose of this short-term risk evaluation was not to draw conclusions, the panel members did not think the SPR Project should take this operational course of action. The panel members expressed the concern that the risk of enhanced mine instability, resulting from a partially empty (non brine-filled) mine, was substantial. The observed high level of surface subsidence on mine stability was considered by the panel to provide a comparable risk to that risk associated with leaving a large quantity of oil entrapped in the mine. Supported by this "High"

Table 8. Potential Short-Term Operational Risk of (Optionally) Delaying Mine Brine Fill to Skim More Oil			
RISK Event:	**Average CONSEQUENCE** (DOE Severity Category)	**Average LIKELIHOOD** (DOE Probability Category)	**Average RISK** [Risk, range] (DOE Risk Category)
4	$69,000,000 ± $49,000,000 (Catastrophic+)	25% ± 37% (Likely)	**$17,000,000 ± $18,000,000** [$0 - $35,000,000] **(High)**

risk evaluation (reported to DOE in draft form, shortly after the risk assessment panel meeting) and associated operational concerns, the SPR Project initiated mitigation actions, by quickly re-starting mine brine filling operations. As a result, the short-term potential operational risk has been minimized or avoided.

In summary, this long-term, environmental risk assessment study, making use of the semi-quantitative Delphi methodology, has provided useful results for the DOE SPR Project that can be openly referenced and evaluated further, as needed. This risk evaluation study has been based on as much relevant information as possible, as presented to the knowledgeable risk assessment panel members, including site and underground observations, subsidence measurements, supporting modeling calculations, and other supporting details on the risk scenarios. The risk assessment results presented in this report can be used to defensibly support or bolster future DOE SPR Project decisions, particularly as related to risk minimization and regulatory compliance-environmental assessment issues.

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